Development of Chemical CO₂ Solvent for High-Pressure CO₂ Capture (4):
Potentiality for Low-Temperature Regeneration

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Abstract

Carbon dioxide (CO₂) capture and storage (CCS) technologies have received much attention as a measure to prevent the global warming, and there are many studies for CO₂ separation to capture. The chemical absorption method utilizing amine solutions is well-known and one of the most important industrial methods used in the CO₂ capture processes, and many investigations have been undertaken on the CO₂ dissolutions into the amine solutions and modeling simulations of the CO₂ dissolution mechanisms.

High-pressure gas containing high concentration of CO₂ is exhausted from integrated coal gasification combined cycle (IGCC) power plants, and thus amine solutions would be desired to provide high performances for CO₂ capture under high-pressure conditions. Aqueous solutions of N-methyl-diethanolamine (MDEA) and Selexol® are well known as the solvents for high-pressure CO₂. However, the CO₂ separation processes with these CO₂ solvents commonly include a depressurization step for desorption of the absorbed CO₂. The depressurization step increases total energy for the CO₂ capture process, because the captured CO₂ with the depressurization step is required to repressurize for transportation and storage.

To reduce the total energy for the CO₂ capture process, including a compression process, we are focusing attention on high performance chemical CO₂ solvents that are regenerable under high CO₂ partial pressure conditions; these solvents are called “High-Pressure-Regenerable (HPR) CO₂ Solvents”. The regeneration of CO₂ solvent under high pressure, which means a thermal swing process under high-pressure without depressurization, leads to significant reduction in the energy consumption for the compression process after CO₂ capture, because the captured CO₂ preserves its pressure high. We know that the aqueous solutions of tertiary amines such as MDEA have low CO₂ absorption heats through the CO₂ separation process because tertiary amines absorb CO₂ to conform bicarbonate ion, and relatively high performances in CO₂ desorption step, despite relatively low performances in CO₂ absorption step. The aqueous solutions of tertiary amines, therefore, have not used as the chemical CO₂ solvents under ordinary pressure owing to the poor absorption capability. However, tertiary amines are thought to be suitable for high-pressure conditions because high-pressure enhances the CO₂ absorption step.

In this report, our development concept of the HPR solvents and the current development status on these solvents are introduced, and the potentiality for low-temperature regeneration of the HPR solvents are discussed by evaluating the performances for CO₂ capture with the HPR solvents under low-temperature up to 100 °C.

We previously reported that two kinds of high-performance HPR solvents, RH-1 and RH-2a, had been found through screening tests; these solvents were amine aqueous solutions.¹ These results denote that RH-1 has a higher desorption rate and a lower CO₂ absorption heat, and RH-2a has higher CO₂ absorption and desorption rates and a higher CO₂ loading-difference, in comparison
to an MDEA solution. Additionally, we have developed RH-2b by optimization of the amine concentration of RH-2a. RH-2b shows 2.4 times higher CO₂ absorption rate, 3.3 times higher desorption rate, and 5.8 times higher loading-difference, with lower CO₂ absorption heat than the MDEA solution. The total energies for a CO₂ capture process, including a compression process, with RH-1 and RH-2b had been calculated using the measured values of CO₂ loading-differences and CO₂ absorption heats. RH-1 and RH-2b are estimated to reduce the total energy to 2.0 GJ/t-CO₂ and 1.9 GJ/t-CO₂, respectively. The HPR solvents are able to desorb CO₂ under a higher pressure than the absorption pressure. An application of the pressurized desorption process to 4.0 MPa-CO₂ is estimated to reduce the total energy of RH-2b to 1.6 GJ/t-CO₂, meaning a 34% reduction from that with the MDEA solution.⁴

Additionally, to reduce the total energy for a CO₂ capture process, including a compression process, a part of water contained in RH-2b has been substituted with organic media. We have found that some organic media having certain functional groups provide performance-improving effects on RH-2b, thus the solutions added these organic media have been defined as RH-3 series, which were previously reported.⁵ The additions of these organic media lead to increases in CO₂ absorption rate and decreases in CO₂ absorption heat. Especially, RH-3e is showing higher reaction rates with very lower CO₂ absorption heat. The total energy for a CO₂ capture process, including a compression process, with RH-3e decreases to reach almost 1.4 GJ/t-CO₂. In addition, by the application of the pressurized desorption process to 4.0 MPa-CO₂, the total energies with RH-3e are reduced by approximately 0.3 GJ/t-CO₂ to less than 1.1 GJ/t-CO₂, which decreases by 56% of that with the MDEA solution.

We have made gas-liquid equilibrium tests under high-pressure conditions for the HPR solvents at the test temperatures of 100 °C and 120 °C. CO₂ loading-differences of RH-2b depending on the temperature for CO₂ desorption are shown in Figure 1. The CO₂ loading-difference between 40 °C and 100 °C has been ascertainment to decrease 34% of that between 40 °C and 120 °C under 1.6 MPa-CO₂. The energy consumption as sensible heat of CO₂ solvent is increased owing to the decrease in CO₂ loading-difference. However, because the energy consumption as latent heat by vaporization is decreased owing to the decrease in desorption temperature, the total energy for CO₂ capture process including compression process to 7.2 MPa-CO₂ is nearly unchanged (increase less than 1% as the net). Therefore, significant reduction in the cost for CO₂ capture is expected, because lower-temperature steam is available at a lower-cost as the heat source. Additionally, the decrease ratio in the concentration of amine in the HPR solvent at 100 °C, which is attributed to deterioration by heat, has been ascertained to decrease 36% of that at 120 °C. It means that the life-span of the HPR solvent is increased to 1.5 times.